Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

THE TRANSPIRATION OF APPLE LEAVES INFECTED WITH GYMNOSPORANGIUM[1]

HOWARD S. REED AND J. S. COOLEY

(WITH ONE FIGURE)

The present paper reports the results of some studies upon the transpiration of apple leaves infected with the cedar rust fungus, *Gymnosporangium Juniperi-virginianae* Schw. Observation of trees attacked by this fungus shows that changes involving serious injury to the economy of the trees are produced. Such trees usually show characteristic dwarfing of both trunk and fruit.

The writers have undertaken to make some quantitative physiological studies upon these diseased trees as a part of a general pathological problem.

The study of the causative organism is highly important for plant pathology if any prophylactic measures are to be taken, but the reaction of the host is also a factor of importance if the action of the parasite is to be understood, or if efficient remedial measures are to be applied. The interest of the cultivator is principally in the host, but up to the present time that of the plant pathologist has been chiefly centered in the parasite. It is believed, however, that a physiological-pathological study of the host will yield results of no less interest than those of a strictly mycological nature.

A survey of the published work upon transpiration discloses few studies of the transpiration of diseased plants, although the assumption is frequently made that the rate of transpiration is affected by the presence of disease.

BLODGETT[2] has reported an observation upon the transpiration of excised branches of *Rubus* sp. infected with *Gymnoconia interstitialis*. In a given period (apparently shorter than 24 hours) the rusted branch absorbed 42 cc. of water, while a healthy branch possessing an equal number of leaves absorbed only 23 cc. of water under similar conditions. In spite of the greater amount of water absorbed, the rusted shoot was more or less flaccid, while the healthy shoot maintained a turgid condition. This behavior might be regarded as a consequence of the condition produced by the caeoma type of sorus produced by the fungus in question. The rupture of more or less extensive areas of the ventral epidermis of the leaf obviously facilitates the evaporation from the spongy parenchyma layers. Possibly other factors connected with the diseased condition may also operate to cause increased transpiration.

---

[1] Paper 24 from the Laboratory of Plant Pathology, Virginia Agricultural Experiment Station.

[2] BLODGETT, F. H., Transpiration of rust-infected *Rubus*. Torreya 1:32. 1901.

While not strictly parallel, it may be proper in this connection to cite results which BURGERSTEIN[3] obtained with the use of dilute solutions of camphor. He found that solutions containing about one part of camphor per thousand had an accelerating influence upon most plants investigated. Excised shoots, which were previously allowed to become somewhat wilted, revived more quickly when placed in camphor water than when placed in distilled water. By weighing the vessels of water in the two cases, it was shown that transpiration from the shoots went on more rapidly in camphor water than in distilled water. That camphor was absorbed by the excised shoots was shown by their pathological condition and death prior to the appearance of any such conditions in the parallel series in distilled water. It seems proper to regard this result as an example of transpiration under pathological conditions, since the deleterious substances thrown off by fungi may act similarly to the camphor.

Results of a somewhat similar import have been reported by one of the authors of this paper, showing that substances like tannic acid and pyrogallol when present in small amounts accelerate transpiration.[4] Small amounts of oxalic and acetic acids were likewise shown to accelerate transpiration. Since these substances are found as such in plants, it is possible that they may influence transpiration more or less independently of other factors.

The studies upon transpiration herein described were conducted upon the apple varieties York Imperial and Ben Davis in orchards near Middletown, Virginia, in 1911 and 1912. All of the trees upon which studies were made were more than eight years old, and, aside from a certain amount of dwarfing due to continued attacks of cedar rust in one of the orchards, the trees were in good physiological condition.

---

[3] BURGERSTEIN A., Über einige physiologische und pathologische Wirkungen des Kampfers auf die Pflanzen, inbesonders auf Laubesprosse. Verh. Kais. Kön. Zoolog.-Botan. Gesells. Wien **34**:543. 1884.

[4] REED, H. S., The effect of certain chemical agents upon the transpiration and growth of wheat seedlings. BOT. GAZ. **49**:81. 1910.

The time available for making satisfactory studies on transpiration of the diseased leaves was restricted to a period of about five weeks beginning near the middle of July. Before that date the cedar rust had not developed sufficiently to derange seriously, or at least uniformly, the activity of the apple leaves. Subsequent to this period, the fungus has injured or even killed more or less extensive areas in the infected leaves, and, in cases of severe infection, the leaves begin falling during the latter part of August.

The work here reported was carried out on leaves and twigs on the trees in their normal position. This method was believed to be preferable, since it has been shown by FREEMAN[5] that actively transpiring shoots do not usually transpire at a normal rate when removed from their own roots.

The data reported in the present paper were obtained by inclosing a few apple leaves in a glass cylinder and absorbing the exhaled water with weighed calcium chloride. The method of carrying on the experiments will be evident from the accompanying sketch of the apparatus (fig. 1), which is a type modified from that of FREEMAN (*loc. cit.*) and others.

In its essentials the apparatus consisted of three parts: a wide mouth glass jar (*A*) which contained the twig under experimentation, a calcium chloride tube (*B*), and an aspirator (*C*) which drew a known volume of air through the apparatus. The glass jar (*A*) was fitted with a soft rubber stopper which was cut through about three-fourths of its diameter. The opposing surfaces were notched at the center of the stopper to allow a twig to pass through, but the notch was small enough to insure a tight fit and prevent the passage of air. Two perforations in the stopper allowed glass tubes of 5 mm. diameter to pass. Tube 1, through which the air entered, extended to within 1 cm. of the bottom of the jar; tube 2, through which air left the jar, extended only about 1 cm. inside of the stopper. Tube 2 was connected with rubber tubing to a glass-stoppered calcium chloride tube (*B*). The calcium chloride tubes were accurately weighed at the laboratory before and after each experiment. The ground stoppers (*3*, *3*), when turned, effectually closed the tubes.

---

[5] FREEMAN, G. F., A method for the quantitative determination of transpiration in plants. BOT. GAZ. **46**:118. 1908.

The aspirator for drawing air through the apparatus was a bottle of 19 liters capacity fitted with a siphon through which the flow could be regulated by means of a screw clamp (*4*). Three sets of apparatus were constructed and carried in a spring wagon which could be moved from tree to tree as occasion required.

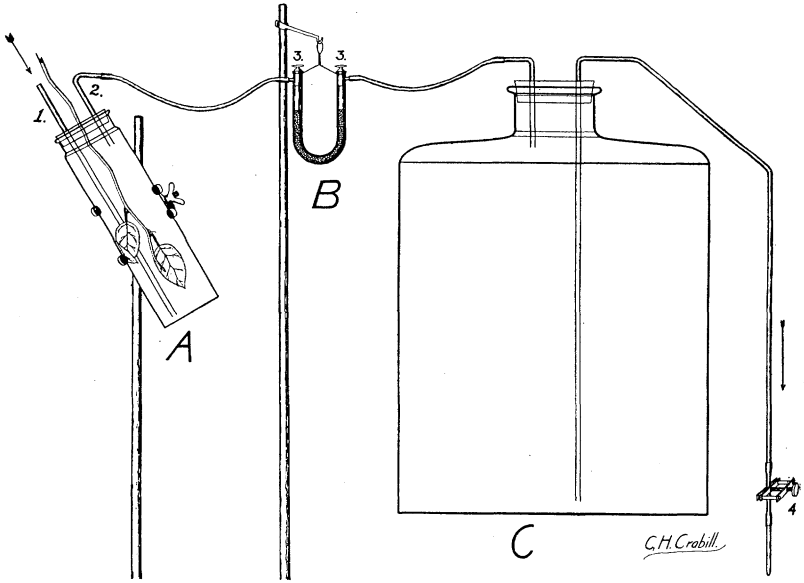

FIG. 1.—Apparatus for measuring transpiration: explained in text

The manner of conducting an experiment was as follows. The apparatus was placed at a tree where direct rays of sunlight would not strike it. A twig bearing leaves suitable for experiment was selected and inserted in the cleft rubber stopper, precautions against bruising or injuring the bark being used. In some cases one or two leaves had to be removed from the twig in order to make a good adjustment. After a few trials it was found that not more than two apple leaves could be used in an experiment with a moderate rate of aspiration; if more were used, water would sometimes collect in the jar *A*. A thermometer was inserted in the jar with the twig, or suspended close to it. The previously weighed U-tube was connected on one side with tube 2 and on the other with the aspirator *C*, which contained 19 liters of water. Care was taken that the temperature of the water used in the aspirator should be very close to that of the air. When the siphon was started, the stoppers (*3*, *3*) were turned to allow air to flow through the apparatus. The flow of water could be regulated by means of the screw clamp (*4*) after a little experience, so that the time required to draw out 19 liters should be close to an hour.

The first apparatus was set up with healthy leaves in the jar *A*; another experiment was similarly set up with leaves infected with cedar rust; a third experiment was set up but with the omission of the jar *A*. These three, each with its own aspirator, were started as nearly simultaneously as possible, and the temperature kept uniform. The purpose of the third set of apparatus was to determine the amount of moisture in 19 liters of air.

The criticism might justly be made that the evaporating power of the atmosphere was not taken into strict account by this sort of an experiment. If the purpose had been to study the conditions or amount of transpiration, such determinations should have been made, but the purpose was to study the comparative transpiration of the healthy and diseased apple leaves, and as such it is believed to fulfil its purpose. Another possibility of error might be found in the vapor pressure from the water in *C*, which would carry back some moisture into the tube *B* and cause the results to be too large. This source of error, however, is obviated by the use of the blank, whose increase in weight was subtracted from each of the accompanying tests.

As soon as the aspirator ceased running, the glass stoppers of the U-tubes were closed and the time noted. The leaves were plucked from the twig, placed in a labeled envelope, and taken to the laboratory along with the set of U-tubes. After weighing the tubes and computing the gain in weight, the necessary correction was made for the moisture absorbed from sources other than the leaves as registered by the increase in weight of the blank.

The outline of the leaves used was carefully traced on paper and the area measured with a planimeter. The results thus obtained were computed and expressed as grams of water transpired per hour per sq. cm. A sample record sheet is herewith given, showing the records as made in the field.

TRANSPIRATION TEST NO. 2
July 13, 1912
Healthy York Imperial leaves

Temperature	30.5° C.
No. of leaves in test	1
Area of leaves	21.3 sq. cm.
Vol. of air used	19 liters
Exper't began	10:18 A.M.
Exper't ended	11:20 A.M.
Duration	62 min.
Final wt. of tube	91.555 gm.
Initial wt. of tube	91.185 gm.
Difference	0.370 gm.
Water in equiv. vol. air	0.291 gm.
Water from leaves	0.079 gm.
Water per hr. per sq. cm	0.0036 gm.

TRANSPIRATION TEST NO. 3
July 13, 1912
Diseased York Imperial leaves

Temperature	30.0° C.
No. of leaves in test	1
Area of leaves	35.2 sq. cm.
Vol. of air used	19 liters
Exper't began	10:14 A.M.
Exper't ended	11:16 A.M.
Duration	62 min.
Final wt. of tube	99.675 gm.
Initial wt. of tube	99.297 gm.
Difference	0.378 gm.
Water in equiv. vol. air	0.291 gm.
Water from leaves	0.087 gm.
Water per hr. per sq. cm	0.0023 gm.

There were 52 determinations made upon healthy and diseased leaves of the York Imperial and 26 upon leaves of the Ben Davis. The results are presented in tabular form in tables I and II.

An inspection of the tables shows that the unit transpiration of the diseased leaves of both varieties of apples was in the majority of cases less than that of the healthy, although exceptions are to be noted. Some of these discrepancies may have arisen from unguarded errors of manipulation, but it is not probable that all are due to such cause.

It is not apparent that the ratio between the transpiration in the healthy and diseased leaves was subject to any regular hourly variation. The unit transpiration in each case naturally varied from hour to hour, but the ratios were in general the same at any given period of the day.

The average ratio of transpiration in the diseased and healthy

TABLE I

TRANSPIRATION OF DISEASED AND HEALTHY YORK LEAVES

No.	Date	Hour at which experiment began	Transpiration of healthy leaves in gm. per hr. per sq. cm.	Transpiration of diseased leaves in gm. per hr. per sq. cm.	Percentage of water transpired by diseased leaves
	1912				
1	July 9	3:27 P.M.	0.00627	0.0064	103.6
2	9	4:15 P.M.	0.00257	0.00203	78.6
3	10	9:10 A.M.	0.0022	0.0033	150.0
4	10	10:20 A.M.	0.0074	0.0069	93.2
5	10	2:20 P.M.	0.0039	0.0043	110.3
6	10	3:50 P.M.	0.0041	0.0040	97.5
7	12	9:30 A.M.	0.0057	0.0065	114.0
8	12	10:45 A.M.	0.0134	0.0071	52.9
9	12	2:45 P.M.	0.0046	0.0048	104.3
10	12	4:05 P.M.	0.0079	0.0040	50.6
11	13	9:03 A.M.	0.0083	0.0106	127.7
12	13	10:14 A.M.	0.0036	0.0023	63.9
13	13	1:38 P.M.	0.00403	0.0043	106.7
14	15	9:06 A.M.	0.00508	0.0082	161.4
15	15	10:07 A.M.	0.0079	0.01033	130.7
16	16	10:20 A.M.	0.0257	0.0095	36.9
17	17	1:45 P.M.	0.0102	0.0078	76.4
18	17	3:00 P.M.	0.008	0.0022	31.4
19	17	8:17 A.M.	0.0102	0.0057	56.0
20	17	9:40 A.M.	0.143	0.0096	67.1
21	22	8:50 A.M.	0.0063	0.0028	44.4
22	22	9:50 A.M.	0.006	0.00505	84.2
23	22	1:50 P.M.	0.0101	0.00718	71.1
24	22	2:57 P.M.	0.0116	0.0088	75.1
25	23	8:38 A.M.	0.00505	0.0029	57.4
26	23	9:55 A.M.	0.00863	0.00573	66.4
27	23	2:45 P.M.	0.0104	0.00808	77.7
28	23	1:53 P.M.	0.0171	0.00589	34.4
29	25	2:35 P.M.	0.00617	0.00465	75.3
30	25	1:40 P.M.	0.0058	0.00425	73.3
31	26	9:30 A.M.	0.00908	0.0066	71.3
32	26	8:30 A.M.	0.0056	0.00439	78.4
33	26	1:35 P.M.	0.00737	0.006638	90.1
34	26	2:25 P.M.	0.00743	0.00408	54.9
35	27	9:25 A.M.	0.0105	0.0072	68.6
36	27	2:10 P.M.	0.0079	0.00606	76.7
37	Aug. 15	3:10 P.M.	0.0057	0.00335	58.8
38	15	4:30 P.M.	0.00445	0.0011	24.8
39	16	10:33 A.M.	0.00562	0.00375	66.7
40	16	2:45 P.M.	0.0055	0.0051	92.9
41	16	4:17 P.M.	0.0148	0.0107	72.3
42	17	9:40 A.M.	0.0047	0.00351	74.8
43	19	8:45 A.M.	0.00508	0.0025	49.2
44	19	3:20 P.M.	0.0055	0.0060	109.1
45	19	4:33 P.M.	0.0104	0.00706	67.9
46	20	10:54 A.M.	0.5003	0.0034	64.1
47	20	2:18 P.M.	0.002918	0.002908	99.6
48	20	3:35 P.M.	0.0036	0.00248	68.3

TABLE I—*Continued*

No.	Date	Hour at which experiment began	Transpiration of healthy leaves in gm. per hr. per sq. cm.	Transpiration of diseased leaves in gm. per hr. per sq. cm.	Percentage of water transpired by diseased leaves
49	1911 July 26	4:00 P.M.	0.0025	0.0022	88.0
50	27	10:03 A.M.	0.0052	0.0043	82.7
51	27	2:14 P.M.	0.0024	0.0019	79.2
52	27	3:30 P.M.	0.0029	0.0016	62.1

TABLE II

TRANSPIRATION OF HEALTHY AND DISEASED BEN DAVIS LEAVES

No.	Date	Hour at which experiment began	Transpiration of healthy leaves in gm. per hr. per sq. cm.	Transpiration of diseased leaves in gm. per hr. per sq. cm.	Percentage of water transpired by diseased leaves
60	1912 July 11	9:40 A.M.	0.0101	0.009	89.1
61	11	10:27 A.M.	0.0101	0.0056	55.4
62	11	2:24 P.M.	0.0128	0.0073	57.0
63	11	3:40 P.M.	0.0094	0.0048	51.0
64	19	9:50 A.M.	0.0065	0.0032	49.2
65	19	8:40 A.M.	0.0032	0.0026	81.25
66	19	12:49 P.M.	0.0065	0.00305	46.9
67	19	1:50 P.M.	0.0043	0.00406	94.4
68	20	9:54 A.M.	0.0041	0.0025	61.0
69	20	8:45 A.M.	0.0042	0.0020	47.6
70	20	1:50 P.M.	0.0031	0.0037	119.3
71	29	2:20 P.M.	0.00675	0.00597	88.4
72	29	3:25 P.M.	0.00913	0.0066	72.5
73	30	9:20 A.M.	0.0053	0.0041	77.2
74	30	8:20 A.M.	0.00574	0.00409	71.2
75	30	2:44 P.M.	0.0100	0.00442	44.2
76	30	2:45 P.M.	0.0061	0.0045	73.8
77	Aug. 22	10:44 A.M.	0.0065	0.0045	69.2
78	22	3:08 P.M.	0.00638	0.0042	65.8
79	22	4:20 P.M.	0.0028	0.0034	121.4
80	23	9:28 A.M.	0.0044	0.0034	77.3
81	1911 July 22	3:45 P.M.	0.00243	0.0017	68.7
82	24	2:46 P.M.	0.0075	0.0039	52.0
83	24	2:57 P.M.	0.0067	0.0023	34.3
84	25	11:00 A.M.	0.0039	0.0061	156.4
85	25	3:45 P.M.	0.0079	0.0046	58.2

leaves comes out very nearly the same in each variety of apple studied, 78.3 for the York and 74.2 for the Ben Davis.

The ratios show certain differences if they are grouped according to periods covering different stages in the development of the disease. The first, from July 1 to 15, is a stage in which the fungus is still immature. At that time none of the peridia have broken open, although the thickened cushions are abundant. The second period, from July 17 to 31, marks a time in which the fungus has reached maturity and the leaf of the host begins to exhibit indications of serious injury. The diseased leaves at this time, owing to the expansion of the ventral surfaces by the cluster cups, are rolled toward the dorsal surface. During this second period many peridia open for the liberation of aecidiospores. The third period studied, August 15 to 23, covers a time in which the full effects of the fungus upon its host were very manifest. At that time many of the infected leaves had fallen from the trees, or, if they remained, they had a greater or less proportion of dead tissue. In table III the percentages of water transpired in these three periods are given.

TABLE III

TRANSPIRATION BY PERIODS

Percentage of water transpired by diseased leaves

Dates	York Imperial	Ben Davis
July 1–16..........	94.7	69.1
17–31..........	66.5	71.3
Aug. 15–23..........	70.7	83.4
For entire time of the experiments.......	78.3	72.4

From these figures it appears that in the first period the average unit transpiration of the diseased York leaves was nearly as great as that of the healthy leaves. In the second period the ratio dropped to 66.5, and rose to 70.7 in the third period. The ratios in the case of the Ben Davis leaves did not materially vary from the first to the second periods, but they showed considerable rise in the third period.

The rusted Ben Davis leaves used in the experiments had an average of 7.7 infections per sq. cm.; the York leaves had an average of 5.7 per sq. cm.

Part of the improvement in unit transpiration observed in August is no doubt due to the fact that the most seriously infected leaves (comparable to those used in the foregoing periods) had fallen off, and less seriously infected leaves were used as test objects.

Attention may also be directed to the problem of diminished unit transpiration of these diseased leaves and its causes. The fungus may work in one or more ways to diminish transpiration, either by its intoxicating action upon the host cells or by causing hypertrophy which alters the normal activities of the leaves. Each of these problems is at present the subject of further investigations. Without going into a study of the cytomorphology of the diseased leaves at this time, it may be said that the portions of the apple leaves bearing cluster cups are three to four times the normal thickness. Their hypertrophy is, as REYNOLDS[6] has reported, chiefly the result of changes in the spongy tissue (parenchyma), by which the loose tissue with large intercellular spaces is replaced by large columnar cells with no intercellular spaces. Stomata are scarce or lacking and the substomatal cavities are altogether lacking. This closure of the intercellular spaces of the leaf diminishes the opportunity for water elimination from the interior of the leaf and consequently affects the transpiration. This may account for the difference between our results and those of BLODGETT previously cited. In the case of the leaves attacked by *G. interstitialis*, the destruction of the lower epidermis facilitates loss of water; while in the apple leaves attacked by *Gymnosporangium Juniperi-virginianae*, the hypertrophy obliterates the stomata and retards the elimination of water.

The retardation of transpiration in the apple leaves studied is believed to have some significance for the study of the real problems concerned with this disease. It has for a long time been known that transpiration and growth are intimately associated. Growth does not usually occur without transpiration. LIVINGSTON[7] and others have shown that in certain instances, at least, transpiration is a reliable index of growth.

Further studies are being made upon the economy of diseased trees, but it is considered that the decreased transpiration of leaves affected with the cedar rust is one factor which may account for the bad physiological condition of such trees.

VIRGINIA AGRICULTURAL EXPERIMENT STATION
BLACKSBURG, VA.

---

[6] REYNOLDS, E. S., Studies of parasitized leaf tissue. BOT. GAZ. **53**:365. 1912.

[7] LIVINGSTON, B. E., Relation of transpiration to growth in wheat. BOT. GAZ. **40**:178. 1905.